Risks of acoustic noise in the MR environment
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Introduction
MRI acoustic noise represents a possible hazard to patients and volunteers undergoing scanning and to workers present in the scanner room during imaging. Vibrations in the gradient coils are generated by Lorentz forces, induced by the currents flowing through the gradient coils within the static magnetic field. The vibrations are transmitted to other parts of the scanner and finally through the air to the ear of the patient or MR worker. In addition noise is also electromagnetically induced in other parts of the scanner because leakage gradient magnetic fields cause eddy currents in other conducting parts of the system [1,2].

Since Lorentz forces are proportional to the current flowing through the coils (hence the gradient amplitude), and the main magnetic field strength, sequences with high spatial resolution, low repetition times or short echo spacing have increased acoustic noise levels [3]. The highest noise levels are normally associated with ultra-fast gradient echo and echo planar imaging pulse sequences.

The frequency spectrum of a MR pulse sequence resembles the Fourier transform of the applied gradient waveforms but filtered by the systems frequency response function (FRF) [4]. Spectra consist of a fundamental frequency at the gradient switching frequency and series of harmonics. Generally the significant components of MR noise range up to a few kHz. The FRF appears as a complex function of peaks and troughs representing the natural frequencies of the gradient coil and other structures of the scanner, generally increasing with frequency. Major resonant peaks are present in the FRF which, if excited by the gradient waveform, lead to much higher noise levels than expected [5]. Access to prominent resonance frequencies will normally be blocked by the manufacturers. There is a broadly linear relationship between worse case acoustic noise (absolute sound pressure) and scanner field strength [3, 6]. In one survey of worst case clinical pulse sequences on a range of MR systems, noise levels varied from 77.2 dB(A)1 on a 0.2 T scanner to 118.4 dB(A) on a 3 T system [3]. Typical noise levels on 1.5 T clinical MRI systems vary from about 80 dB(A) to 110 dB(A) [7].

The noise levels reported above were measured at or close to the isocentre of the scanner however the noise levels experienced by MR workers in the scanner room may also be high enough to exceed national occupational limits depending on their working position and exposure time [8].

Review of effects

Discomfort and stress
Unprotected exposure to excessive noise may cause immediate discomfort and stress. In normal individuals the discomfort threshold is around 120 dB in the range 1 to 5 kHz [9]. However sensitive individuals suffering from conditions such as recruitment or hyperacusis may be discomforted by significantly lower noise levels [10]. Noise acts as a stressor which can cause anxiety and changes in pulse and respiration rate [11]. Noise has been identified as a factor amongst others, such as claustrophobia, in increasing anxiety amongst MR patients [12].

Temporary threshold shift
A short period of unprotected exposure to loud noise can also produce a temporary threshold shift (TTS) in the sensitivity of hearing. This is experienced as a dulling in hearing at the end of the exposure and can be accompanied in some cases by tinnitus. After the exposure ends hearing may return to normal. However if the noise exposure is particularly severe or if it is continually repeated, particularly before a full recovery has occurred, there may be a permanent threshold shift (PTS). The production of temporary threshold shifts in MR patients has been demonstrated by Brummett et al. [13]. Data from non-MR exposures indicate that a clinically significant threshold shift (>10 dB) may be avoided in most cases if noise is below 80 dB(A) and the exposure is limited to under an hour [14, 15]. Helpfully most MR noise is below 4 kHz where the ear is most sensitive to this effect.

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1 Sound pressure level relative to 20μPa on the A-weighted scale used to represent the frequency sensitivity of the human ear.
Permanent threshold shifts and subjective effects

The threshold of instantaneous and permanent acoustic trauma normally associated with exposure to impulsive noise is 140 dB. IEC compliant MR systems cannot produce a peak sound pressure greater than 140 dB [16]. It is generally accepted that noise level of 75 dB(A) will not give rise to any PTS however long the exposure [17]. Therefore between 75 and 140 dB the risk of permanent noise induced hearing loss is related to the intensity and duration. The energy equivalence principle is in widespread use in the estimation of noise hazard [18]. A 3 dB(A) trading rule has been widely accepted. This means that an 85 dB(A) exposure averaged over 8 hours is equivalent to a 30 minute exposure to 97 dB(A).

The potential risk to MR patients and volunteers is unlikely to involve the production of a PTS given the limited exposure time involved. The IEC recommendation that hearing protection is used if noise exceeds 99 dB(A) is based on the prevention of a PTS in patients and volunteers. However workers spending significant amounts of time in the scanner room during imaging without adequate protection may be at risk of a PTS in common with others working in noisy environments.

There is some limited subjective evidence from leisure-related noise exposures and MR adverse incident reports that permanent effects may be induced in unprotected subjects from occasional exposures to loud noise (<140 dB). Tinnitus and hypersensitivity have been reported in individuals exposed to loud noise at music concerts where noise levels may reach 120 dB(A) [19]. These effects may be permanent even after a single exposure. De Wilde et al. reported the case of a patient who suffered hearing loss accompanied by severe unrelenting headaches, ear pains and dizziness after undergoing an MR scan on a 0.5 T system without being given hearing protection [20].

Fetal exposures

A review on the hazard of noise to the fetus and the newborn concluded there was some evidence of shortened gestation and decreased birth weight from excessive noise exposure in pregnancy [21]. Hepper and Shahidullah concluded that any effect on reproductive outcomes from noise is probably indirect due to it’s role as a stressor on the mother and that reducing this stress through the provision of suitable hearing protection may reduce the risks [22].

Hearing protection

Ear plugs and defenders are forms of passive noise control based on absorption. Plugs will only be effective if properly fitted into the ear canal. Problems may occur in this regard if patients are left to fit the plugs themselves. Ear defenders are easier to fit. However they can be found uncomfortable to use in conjunction with some smaller head RF coils. For some clinical applications such as breath-hold scanning good communication between patient and radiographer is essential. MR manufacturers provide earphones for this purpose that attenuate the MR noise whilst allowing communication with staff. Up to 35 dB of protection is offered by plugs and defenders at the frequencies of interest in MR. Both can be worn together if noise is very intense generally providing up to 6 dB of attenuation above the most effective form of protection when worn alone [23].

Summary

Patients and volunteers

There is little risk of a permanent threshold shift in those exposed to MR noise on an occasional basis but certain scans may exceed the discomfort threshold particularly for sensitive individuals. Temporary threshold shifts can be induced if patients and volunteers are not adequately protected which may cause discomfort and be accompanied by other effects such as tinnitus. Clinically significant temporary threshold shifts in MR patients and volunteers are unlikely in most subjects for noise levels below 85 dB(A), given the relatively low frequencies encountered in MR, and the typical examination times of less than an hour. However there are variations in sensitivity between individuals both in terms of the threshold of discomfort and the production of TTS’s. Therefore the UK official guidance states that all patients and volunteers should be fitted with hearing protection unless noise levels can be shown to be comfortably below 80 dB(A) [24, 25].

MR workers

Staff present in the scanner room during imaging on a regular basis may be at risk of permanent hearing damage if not protected adequately. These exposures will fall under national laws and regulations for the control of occupational noise exposure.
References